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CENTRIFUGAL THERMIT PROCESS – AN OVERVIEW

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ABSTRACT: In this paper general concepts about the centrifugal thermit (C-T) process with few illustrative examples are presented. Thermit reactions are carried out under the effect of centrifugal force. The application of centrifugal force in these processes helps in the quick separation of the products of the thermit reaction, if they are of different densities and produced in molten state. If the magnitude of the centrifugal force is inadequate, the products are produced as mixtures. A detailed description of the process carried out such as synthesizing the required product phases, insitu consolidation and castings of aerospace components are reviewed. The advantages and limitations of these methods have been analyzed by considering the property versus degree of conversion dependencies of several reactant systems. A brief introduction to the applications of combustion-synthesized products is followed by a discussion of the methods for fabrication. A few novel techniques based on C-T process, used in aerospace applications are elaborated.

1. INTRODUCTION

Centrifugal-thermit process, also commonly referred to as self propagating high temperature synthesis (SHS) under the influence of gravity, is one of the advanced materials processing technology by which insitu synthesis cum densification of ceramic lining to metal substrates, shaped casting of ceramic composites and intermetallic composites can be produced. Merzhanov and Yukhvid [1] initiated the fundamental research on the process in 1975. This process utilizes the internally generated chemical energy of solid-state starting reagents. The characterization of the gravity influenced synthesis process is depicted in Fig. 1.

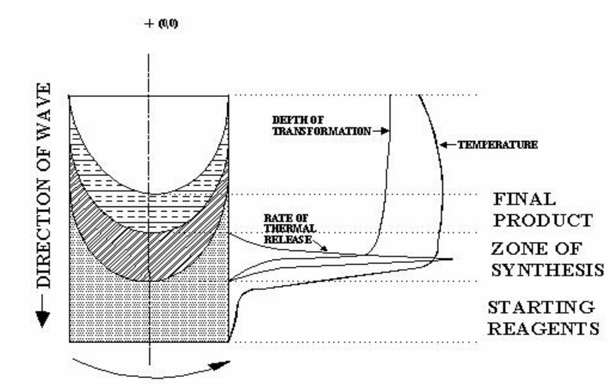
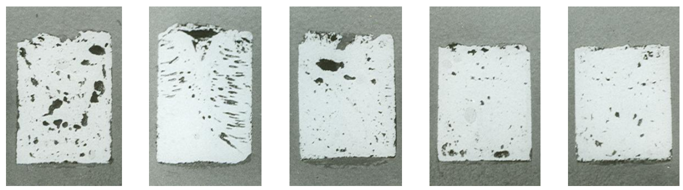


Fig.1. Diagram of the C-T process

As the starting reagents enter the zone of synthesis, the chemical reactions are initiated. The synthesis wave then propagates to the heat release zone where starting reagents are converted into desired products. The rate of wave propagation in this zone is greatly influenced by centrifugal force. The remaining zones complete the reaction and structurization, leading to the formation of the final product phase [2]. The high temperature developed in heat release zone helps in almost complete transformation of the starting reagents into thermodynamically stable product phases with "self -purificationò feature. In this feature evaporation of impurities that are volatile and removal of oxide films on the metal particles by a reduction process takes place. The structurization of the final products of the thermit reaction depends primarily on the ratio of the synthesis temperature to the melting temperature of the final product. Centrifugal forces are of secondary importance.

2. INFLUENCE OF CENTRIFUGAL FORCE ON PRODUCT PHASES

Centrifugal force on thermit process increases the propagation velocity of combustion wave due to the infiltration of molten metallic phases, thus increasing the rate of preheating of the starting reagents. Also, centrifugal force minimizes the overall heat losses of the process. In this paper we discuss the influence of centrifugal force on the combustion regularities and mechanism of moderate-enthalpy heterogeneous system like intermetallic reactants (Ni + Al) both in the melt and product phase. The experiments were performed on a centrifuge in the G = a/g (0-800) over load range, where **a** is centrifugal acceleration and **g** is free-fall acceleration. The graphite capsule was filled with 1gm of homogeneous mixture of powders of Ni and Al and is placed inside a container having thermit mixture (Fe_2O_3 + 2Al). The tests were executed in constant enthalpy regime and all synthesized products were having single phase. The combustion regularities and mechanism were qualitatively assessed by metallogaphic technique.



47G 148G 351G 548G 790G

Fig.2. Influence of centrifugal force on combustion regularities (NiAl system)

The influence of the centrifugal force is on the elimination of the porosity in the intermetallic compounds. It is seen that the displacement of pores is opposite to the direction of combustion or centrifugal force (as shown in Fig.2.). It should be noted that the high magnitude of centrifugal force exerts strong influence in two ways viz., the forced penetration of the liquid combustion products in to the pores of the starting reagents and in replacing conductive heat transfer mechanism into convective one. The criterion for passage from one mode of heat transfer to the other can be written in the form K = Ŭб/ Ŭб ~ 1, where Ŭб and Ŭб are the conductive and convective thermal diffusivity co-efficients and K is the size of the pore. From dimensional analysis we write Ŭб ~ vl, where v and l are the velocity and the depth of penetration of the melt into the pores. It is observed that optimum centrifugal force for densification is purely dependent upon green density of the starting reagents.

3. PROVIDING CERAMIC LININGS TO CIRCULAR METAL TUBES

Fig.3. Allumina Lined Tube

The molten products of the thermit reaction are cast inside a rotating circular metal tube to provide the tube with a ceramic lining, useful for thermal barrier applications (as shown in Fig.3). The process can be repeated to provide the metal tube with thick ceramic lining consisting of multilayers. The steps involved in this process are (a) placing the powder thermit mixture consisting of strongly reducing element and reducible oxide in the tube, (b) rotating the metal pipe around an axis so that the thermit mixture is pressed against the inward surface of the pipe by the centrifugal force to form a layer, (c) igniting the themit mixture, (d) cooling the pipe which has stratified layers of the metal and the oxide. In the production of such ceramic lined tubes, to get dense small-grained microstructure, without sacrificing the high temperature creep and hardness, vacuum centrifugal thermit process can be adapted. Additives in the form of diluents were added to improve the yield of the ceramic, grain growth, thermal shock resistance & product phase purity. However, such additives cause structural changes in the material, e.g., hardness decreased by 30%. Odawara and co-workers [3] have studied this process in detail.

4. PROVIDING CERAMIC LININGS TO AXISYMMETRIC VARIABLE DIAMETER METAL COMPONENTS, SUCH AS A CONE

Fig.4. Allumina lined cones

The molten ceramic product of a thermit reaction is cast inside an axisymmetric variable diameter metal component, such as a cone, rotating about its axis and simultaneously rotating about an external axis to provide the cone with a ceramic lining (as shown in Fig.4.). Many industrial applications require convergent divergent nozzle with corrosion-resistant, abrasion-resistant and heat-resistant ceramic lined metallic conical sections [4].

5. PRODUCING SHAPED COMPONENTS FROM METALS, ALLOYS OR CERAMICS

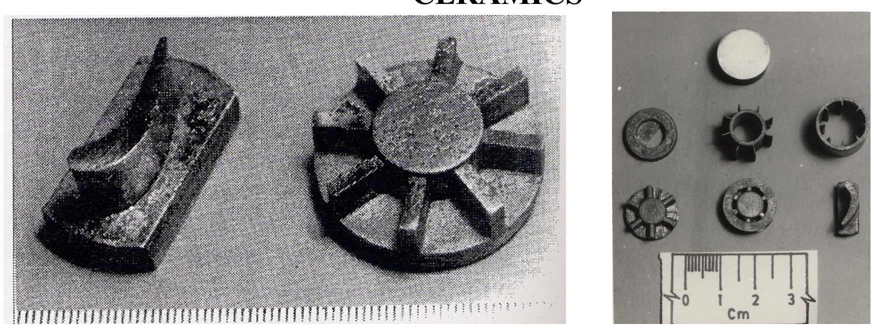


Fig.5. Shaped Casting of Nickel Alluminide

The separated molten product or mixture of products of a thermit reaction is forced into the shaped cavity of a ceramic mould to produce a centrifugally cast shaped component from the product or mixture of products of the thermit reaction (as shown in Fig.5) [5]. 800 gram of ultra high temperature cermet was fabricated through NAL developed Cenrifugal-Thermit process (as shown in Fig.6). Using this process, shaped casting having inside profile of convergent, divergent, cylindrical and external profile of conical & cylindrical (80mm in length, 86mm in diameter and 3mm to 10mm varying wall thickness) was made. These cermets have 95-97% of relative density, hardness of 2300 Vickers hardness number and room temperature thermal conductivity of 14W/mK.

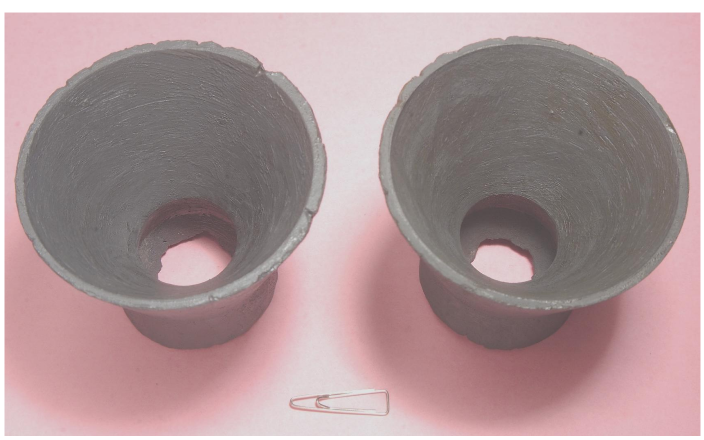


Fig.6. Zirconia based cermet convergent-divergent nozzles

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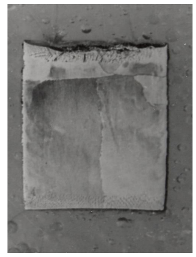
The process developed was simple, less time consuming, low cost and require less energy compared to other existing / competing processes to produce similar aerospace components from advanced materials for critical applications [6].

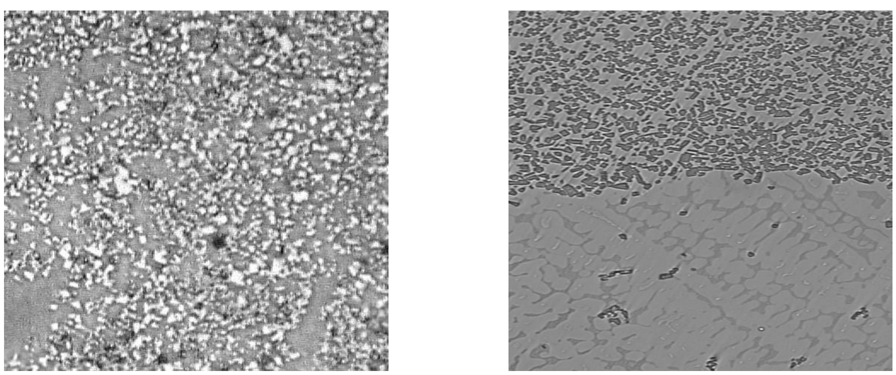
6. SIMULTANEOUS SYNTHESIS AND CASTING OF INTERMETALLICS AND INTERMETALLIC MATRIX COMPOSITES (IMCs)



351G 3X

Fig.7. Ni_3Al Casting

A mixture of starting materials of an intermetallic or an IMC is encapsulated in a conductive ceramic capsule. The capsule is buried in a thermit mixture and the thermit reaction is used as the source of heat (i.e., chemical oven) required for the synthesis of the desired intermetallic or IMC inside the capsule [7]. The product inside the capsule is simultaneously densified by the application of centrifugal force. The process was calibrated using fixed quantities of pure metal powders to know the amount of sensible heat available inside the capsule for the synthesis of an intermetallic. By careful control of heat flow into the capsule, either unidirectional solidified intermetallic or an intermetallic with large grain sizes can be produced by this process [8]. The macrostructure of Ni_3Al having columnar grains grown in a direction opposite to that of heat flow shows the possibility of directional solidification in this process (Fig.7). The microstructure of the IMCs developed through C-T process is shown in Fig.8. Further thermo mechanical treatment makes these castings to be used as end products in making dowels, fasteners and couplings without the secondary process of homogenization.



351G 500X **548G 500X**

NiAl +25 Wt.% TiB_2 Fig.8. IMCs **NiAl +15 Wt.% TiB_2**

7. FORMING CONVERGENT DIVERGENT CERAMIC NOZZLES INSIDE A METAL TUBE OR CONE

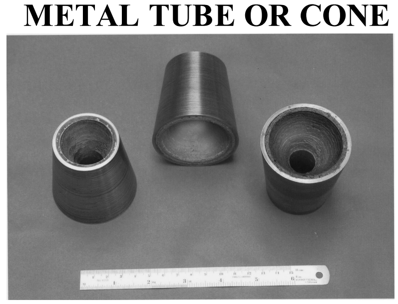


Fig.9. Allumina Convergent Divergent Nozzle

Multilayers of the products of a thermit reaction are deposited inside a metal tube or a cone using ceramic cores at the ends of the tube or cone to form a convergent and divergent nozzle, (as shown in Fig.9) made of a ceramic and metal composite, inside the metal tube or cone [9]. These components are very useful for storage of nuclear wastes and tubular billet crystallizer of continuous casting machine (CCM).

8. CONCLUSION

An over view of centrifugal themit reactions, which are exothermic oxidation-reduction type involving a metal and an oxide or reactant of the intermetallic compounds is explained. The reaction can be initiated by an energy source such as an electric arc, microwave energy, or a mechanical impact. There are two basic modes of thermit reactions: ñpropagatingò and ñbulkò reactions. In C-T process, if the propagating type reaction system is partially converted into bulk mode, they lead to rapidly solidified metastable products with unique properties. If the propagating type reaction system is fully converted into bulk mode, then they lead to thermodynamically stable products with known properties. The major advantage of the C-T process is that the ultra high temperature materials produced in liquid phase during themit reaction when fed into the required mould with aid of centrifugal force can make shaped components using wide range of ceramic composite materials. C-T process generates sufficient vibration energy to stir the liquid product phase and thereby expel the trapped gas voids. The ability to produce composite ceramic materials from cheaper raw materials without the use of sophisticated furnace & press make them highly efficient process. The major limitations are too many interlinked process parameters, complex nature of the dynamic reactor and highly combustible reactants. Further research is needed in order to develop near net shaped products and electrically conductive ceramic composites to overcome the problems associated with scale-up and mass production.

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